

Geometry Based Recursive Algorithm to Control the End Effectors of Coordinated TRRLR Manipulators

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ABSTRACT

A mobile manipulator which is combination of a mobile platform and a manipulator, provides a highly flexible system, which can be used in hazardous application. One of the challenges with mobile manipulators is the construction of control systems, enabling the robot to operate safely in potentially dynamic and all terrain environments. In this paper we will present work in which a mobile manipulator is controlled using the hybrid approach. The method presented is a real time approach in which geometry of the arm with onboard sensor data processing are used both for the overall coordination of the mobile platform and the manipulator as well as the trajectory planning along a straight line parallel to two planes.

Keywords

Recursive algorithm,, end effector, GPR, unmanned ground vehicle, robotic arm

INTRODUCTION

Mobile manipulator systems comprised of a mobile platform with one or more manipulators are of great interest in number of applications. This paper presents a planning and control methodology for such systems allowing them to follow desired end-effector trajectories. Robotic manipulators are being considered for a wide variety of applications outside of their traditional factory settings. These applications, such as fire-fighting, toxic waste cleanup, hazardous explosive material handling and planetary exploration will require the manipulators to operate from moving vehicles, as mobile manipulators. A mobile manipulator, composed of a manipulator arm mounted on a mobile platform, is far more versatile than a conventional manipulator whose base is fixed, as a consequence of its enlarged operational space. Typically, a mobile manipulator's vehicle will have significant dynamic behavior, particularly due to suspension compliance, in contrast to factory manipulators generally mounted on rigid bases. As a result, a mobile manipulator's motions will dynamically interact with those of its vehicle on its suspension to degrade the manipulator's performance. Such problems as excessive end-effector errors and poor system stability can result. The control problems for these systems are further exacerbated by highly variable system characteristics. Hybrid approach is a technique combining the kinematic model of the manipulator and sensor data of platform disturbances with real time closed loop control system.

This paper, describes the construction of TRRLR mobile manipulator for uneven and unknown terrain application. Precise control is required to deploy the arm for hazardous mission from folding condition to the mission position. During the mission it is mandatory to maintain a constant gap between the ground and sensor intended to carry out the mission. Also the sensor should always be at a constant distance from vehicle so that it can scan along a straight line. Then, it represents the kinematics of the system and also the envelope of the manipulator without disturbing the other system. With geometry based principle, a method to control the servo angles of all arm joints to get the desired tip position is discussed.

1. UNMANNED TRACKED GROUND VEHICLE

MOBILE SYSTEM WITH MOBILE MANIPULATOR

Mobile vehicle carrying mine detection sensors fitted on robotic arm controlled from a base station must possess automatic control and tele operation control to successfully complete the mission. The combined two serial arms has to carry the mine detection sensor which is meant to detect buried land mines in unstructured and unknown terrain. It has to be deployed from the frontal edge of the vehicle with adequate standoff distance from the hazardous objects. The manipulator arm has to maintain the constant distance in between the ground surface and mine detection sensor for different orientation of the vehicle and sensor together or separately during the movement of the vehicle on undulated terrain. Precise control is required to protect the expensive sensor from obstacles in the path of unmanned vehicle which carries the robotic arm with sensor

2 SYSTEM DESCRIPTION AND METHODOLOGY

There are two serial arm manipulator fitted in front of the unmanned tracked vehicle. The remote vehicle is controlled from a base vehicle through wireless LAN. The manipulator arms will carry the sensor to detect the buried object under the ground is also remotely operated. But the closed loop control of the end effectors position has to be carried out by an electronic controller system. The suitable control loop to carry out the position control based on the signals from onboard sensors like ultrasonic distance sensors, Inertial Measurement Unit and array of accelerometer will reside in the embedded controller. The each arm has five degree of freedom such as base turret twist (T), back arm rotation (R), fore arm rotation (R), fore arm linear actuation (L) and rotation of end effectors (R). The configuration of this arm is TRRLR and is represented in Figure.1

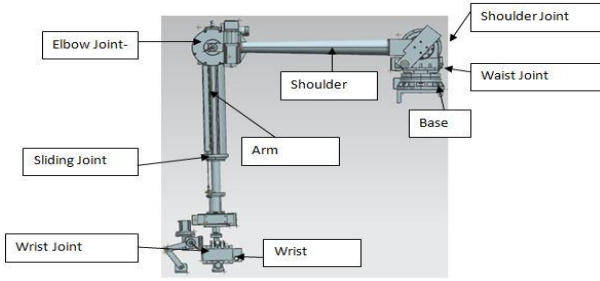


Figure 1 TRRLR mobile manipulator arms with sensor

The gap between the ground surface and the sensor as in figure 2 is maintained by measuring the distance with ultrasonic sensors. When any presence of mines is detected the arm will scan the area to identify the exact location of the mine so that the area over which mine is present can be found out. A geometry based recursive algorithm is used for trajectory control of the sensor attached to the manipulator. When the back arm is rotated through an angle θ , the x and y coordinates varies with the z axis remaining constant. Now to bring the x axis back to the desired position, fore arm has to be rotated through an angle ϕ which depends on the variation in x-axis, δx . When fore arm rotates there will be variations along x,y and z directions. The end effector lifts up by δz . Now the linear actuator extends by a length δz bringing it back. The algorithm is continued till the y-axis reaches the desired limit. Inclination angle α and Φ in the plane of roll and pitch as shown in Figure 2. Based on these results the corresponding joint actuators are rotated to make the mine detection sensor optimally parallel to the ground undulations. The geometry based analysis of the arm is utilized to ensure the safety of the sensor mounted on the arm from unknown terrain obstacle when the unmanned vehicle is deployed for the mine detection mission. The fig 3 shows the required dexterity of the end effectors mounted with the sensor. Obstacle detection sensor is mounted on the frame carried by the robotic arm along with the sensor

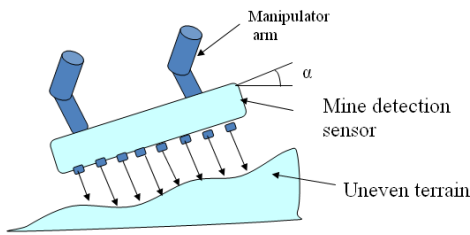


Figure 2 Measurement of unevenness of the ground

3. KINEMATICS OF THE MANIPULATOR

3.1 FORWARD KINEMATICS

In manipulator system, five Degree of freedom jointed arm configuration Twist-Revolute-Revolute-Linear-Revolute (TRRLR) is designed to carry the sensor and marking unit at the end effectors. The forward kinematics of the single arm is represented as below in fig 4. The Denavit - Hartenberg parameters have been worked out for this configuration as shown in table 1. It represents the link parameters like link rotation θ_i , link length a_i , link twist α_i and link offset d_i

Table 1: D-H parameters of manipulator

Joint	θ_i	α_i	a_i	d_i
1	θ_1	90	0	0
2	θ_2	0	a_2	0
3	θ_3	90	0	0
4	θ_4	0	0	d_4+L
5	θ_5	-90	0	0

By multiplying sequentially the transformation matrices from the initial frame to the end-effectors frame. The transform matrix for the four joint as arrived in equation 1 to 6

$$T_5^0 = T_1^0 T_2^1 T_3^2 T_4^3 T_5^4 \quad (1)$$

$$T_{10} = \begin{bmatrix} \cos\theta_1 & 0 & \sin\theta_1 & 0 \\ \sin\theta_1 & 0 & -\cos\theta_1 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (2)$$

$$T_{21} = \begin{bmatrix} \cos\theta_2 & -\sin\theta_2 & 0 & \cos\theta_2 \\ \sin\theta_2 & \cos\theta_2 & 0 & \sin\theta_2 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (3)$$

$$T_{32} = \begin{bmatrix} \cos\theta_3 & 0 & \sin\theta_3 & 0 \\ \sin\theta_3 & 0 & -\cos\theta_3 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (4)$$

$$T_{43} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & d_4 + L \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (5)$$

$$T_{54} = \begin{bmatrix} \cos\theta_5 & 0 & -\sin\theta_5 & 0 \\ \sin\theta_5 & 0 & \cos\theta_5 & 0 \\ 0 & -1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (6)$$

The position of the end effector is found after multiplying the above matrices and is given in the following equations

$$X = (\cos(\theta_1) * \cos(\theta_2) * \sin(\theta_3) * (d_4+L) + (\cos(\theta_1) * \cos(\theta_3) * \sin(\theta_2) * (d_4+L)) + (\cos(\theta_1) * \cos(\theta_2) *)) \quad (7)$$

$$Y = (\sin(\theta_1) * \sin(\theta_3) * \cos(\theta_2) * (d_4+L)) + (\sin(\theta_1) * \sin(\theta_2) * \cos(\theta_3) * (d_4+L)) \quad (8)$$

$$Z = (\sin(\theta_2)) * \sin(\theta_3) * (d_4+L) - (\cos(\theta_2) * \cos(\theta_3) * (d_4+L)) + \sin(\theta_2)) \quad (9)$$

4 GEOMETRICAL RECURSIVE ALGORITHM

4.1 GEOMETRY BASED RECURSIVE ALGORITHM CONTROL SCHEME

It is essential to move the mine detection sensor in the straight line like moving the sensor only in y direction alone and similarly, move the sensor only in z direction. It can be achieved by means of the geometrical algorithm that the joint coordinates can be calculated. It is possible to dictate the manipulator movement in a straight line by specifying the x, y and z distance. Once the final target is known, further work out the angle of rotation for rotary joints and displacement for linear joints are arriving by means of the equations as shown in eqn (5) , (6) and (7)

Clockwise motion $y=0$ to $y=.750$
 $\theta_{found} = \theta_{found} + \theta_{step}$ (10)
 $x_0 = (L_0 + d * \sin(\alpha_{previous})) * \cos(\theta_{found})$ (11)
 $y_0 = (L_0 + d * \sin(\alpha_{previous})) * \sin(\theta_{found})$ (12)
 $z_0 = z$ (13)
 where displacement is the step size along y axis.

Now when fore arm is rotated,
 $\alpha_{found} = \text{asin}((L_0/L_1) * (1 - \cos(\theta_{found}))) / \cos(\theta_{found})$ (14)
 $x_1 = (L_0 + (L_1 * \sin(\alpha_{found}))) * \cos(\theta_{found})$ (15)
 $y_1 = (L_0 + (L_1 * \sin(\alpha_{found}))) * \sin(\theta_{found})$ (16)
 $z_1 = -L_1 * \cos(\alpha_{found})$ (17)

With the rotation of forearm, the end effector rises up by Δz . So to bring it back linear actuator is used. The linear actuator is extended by Δz

$\Delta z_1 = \text{abs}(z_1(\text{count}) - z_1(\text{count}-1))$ (18)
 $x_2 = (L_0 + (L_1 * \sin(\alpha_{found}))) * \cos(\theta_{found})$ (19)
 $y_2 = (L_0 + (L_1 * \sin(\alpha_{found}))) * \sin(\theta_{found})$ (20)
 $z_2 = -L_1 * \cos(\alpha_{found})$ (21)

Counter clockwise $y=.750$ to $y=0$

$\theta_{1_found} = \theta_{1_found} - \theta_{1_step}$ (22)
 $x_1 = (L_1 + d * \sin(\alpha_{previous})) * \cos(\theta_{found})$ (23)
 $y_1 = (L_1 + d * \sin(\alpha_{previous})) * \sin(\theta_{found})$ (24)
 $z_1 = z_0$ (25)

Fore arm rotation

$\alpha_{found} = \text{asin}((L_0/L_1) * (1 - \cos(\theta_{found}))) / \cos(\theta_{found})$ (26)
 $x_1 = (L_0 + (L_1 * \sin(\alpha_{found}))) * \cos(\theta_{found})$ (27)
 $y_1 = (L_0 + (L_1 * \sin(\alpha_{found}))) * \sin(\theta_{found})$ (28)
 $z_1 = -L_1 * \cos(\alpha_{found})$ (29)
 $L_1 = L_1 - (\Delta z_1 / \cos(\alpha_{found}))$ (30)

Linear actuator actuation

$x_2 = (L_0 + (L_1 * \sin(\alpha_{found}))) * \cos(\theta_{found})$ (31)
 $y_2 = (L_0 + (L_1 * \sin(\alpha_{found}))) * \sin(\theta_{found})$ (32)
 $z_2 = -L_1 * \cos(\alpha_{found})$ (33)

Scanning anticlockwise $0 < y < 2.25$

$X_0 = (L_0 + d * \sin(\alpha_{previous})) * \cos(\theta_{found})$ (34)
 $Y_0 = (L_0 + d * \sin(\alpha_{previous})) * \sin(\theta_{found})$ (35)
 $Z_0 = z_0$ (36)

$\alpha_{found} = \text{asin}((L_0/L_1) * (1 - \cos(\theta_{found}))) / \cos(\theta_{found})$ (37)

$x_1 = (L_0 + (L_1 * \sin(\alpha_{found}))) * \cos(\theta_{found})$ (38)
 $y_1 = (L_0 + (L_1 * \sin(\alpha_{found}))) * \sin(\theta_{found})$ (39)
 $z_1 = -L_1 * \cos(\alpha_{found})$ (40)

Linear actuator

$\Delta z = \text{abs}(z(\text{count}) - z(\text{count}-1))$ (41)
 $L_1 = L_1 + (\Delta z / \cos(\alpha_{found}))$ (42)
 $x_2 = (L_0 + (L_1 * \sin(\alpha_{found}))) * \cos(\theta_{found})$ (43)
 $y_2 = (L_0 + (L_1 * \sin(\alpha_{found}))) * \sin(\theta_{found})$ (44)
 $z_2 = -L_1 * \cos(\alpha_{found})$ (45)

Scanning clockwise $-2.25 < y < -1.5$

$\theta_{found} = \theta_{found} + \theta_{step}$ (46)
 $x_0 = (L_0 + d * \sin(\alpha_{previous})) * \cos(\theta_{found})$ (47)
 $y_0 = (L_0 + d * \sin(\alpha_{previous})) * \sin(\theta_{found})$ (48)
 $z_0 = z_0$ (49)

Forearm movement

$\alpha_{found} = \text{asin}((L_0/L_1) * (1 - \cos(\theta_{1_found}))) / \cos(\theta_{1_found})$ (50)

$$\begin{aligned} x1 &= (L0 + (L1 * \sin(\alpha_{found}))) * \cos(\theta_{found}) \\ y1 &= (L0 + (L1 * \sin(\alpha_{found}))) * \sin(\theta_{found}) \\ z1 &= -L1 * \cos(\alpha_{found}) \end{aligned} \quad (51) \quad (52) \quad (53)$$

$$\begin{aligned} \text{Linear Actuator} \\ \Delta z &= |z0 - z1| \\ L1 &= L1 - (\Delta z / \cos(\alpha_{found})) \end{aligned} \quad (54) \quad (55)$$

$$\begin{aligned} x2 &= L0 + (L1 * \sin(\alpha_{found})) * \cos(\theta_{found}) \\ y2 &= L0 + (L1 * \sin(\alpha_{found})) * \sin(\theta_{found}) \\ z2 &= -L1 * \cos(\alpha_{found}) \end{aligned} \quad (56) \quad (57) \quad (58)$$

5 RESULTS AND DISCUSSION

During the mission mode of mine detection if the sensor identifies land mine in front of the UGV it becomes inevitable to scan the ground for ensuring clear way without any buried land mine like object. To carry out this task precisely the recursive geometry approach makes the Turret motor to rotate in desired step angle followed by Fore arm rotation and prismatic joint displacement to ensure desired trajectory with constant 300mm gap between the radar and ground surface.

Fig 3 to fig 8 shows sequentially the methodological control of the independent and combined arm and controlled trajectories by mean of geometrically worked out spatial movement of the arms

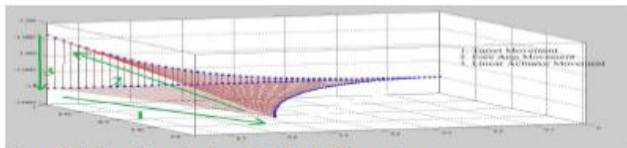


Figure 3 Principle of Scanning From Origin to Positive maximum

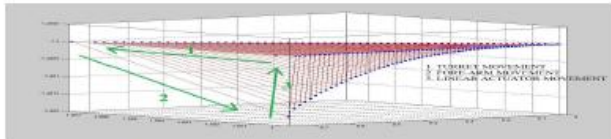


Figure 4 Principle of Scanning From Positive maximum to origin

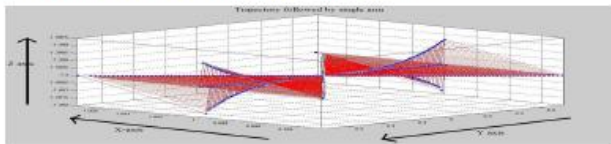


Figure 5 Trajectory Followed by single arm

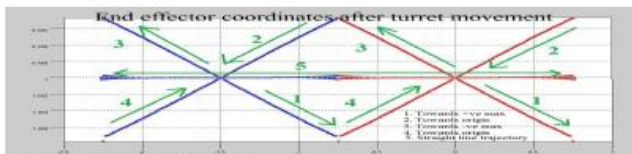


Figure 6 Top View In Either Direction

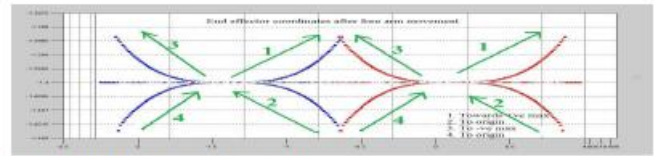


Figure 7 Front View of fore arm movement

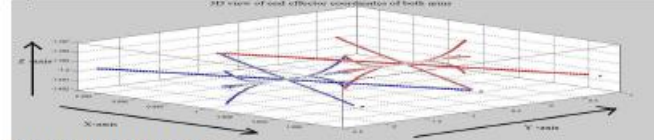


Figure 8 3D view of both arms

6 CONCLUSION

This paper exhaustively addresses the issues related to the control scheme of the mobile manipulator arm to be used on an unmanned tracked vehicle for carrying out hazardous roles in unstructured terrains. The geometry of the single arm is used to control the end effector position. The concept has been developed and simulated in Matlab. This scheme has to be implemented for the real time control of the multiple axes of the arm with hybrid methodology. Different control system methods to be analysed for closed loop precise control of the arm for unstructured environment.

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